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UNITED STATES DEPARTMENT OF AGRICULTURE
Rural Electrification Administration
St. Louis, Missouri (2)

December 1, 1943

SUPPLEMENT TO

ENGINEERING MEMORANDUM NO. 120R

To: All System Engineers and
REA Field Construction Engineers

From: Guy W. Thaxton, Chief
Design and Construction Division

Subject: Calculating Fault Currents on REA Lines

Attached is a copy of "Graphical Method of Calculating Fault Currents on REA Lines," which has been prepared for the purpose of facilitating the calculation of fault currents and the checking of fault current calculations in connection with making sectionalizing studies. It is requested that the graphical method be used wherever possible in making fault current calculations. When you once become familiar with the procedure, you will find that the graphical method has many advantages over other standard methods of calculating fault currents.

The attached bulletin does not cover the entire procedure of making a sectionalizing study. It covers only the calculation of fault currents on the distribution system and does not contain instructions on the calculation of the source and substation impedance, selection of fuses and circuit breakers and other factors which should be considered in making a complete sectionalizing study. It should be used as a supplement to the bulletin entitled, "Procedure for Making a Sectionalizing Study on Rural Electric Systems," which was attached to Engineering Memorandum No. 120R, dated February 4, 1943.

Guy W. Thaxton

Attachment

GRAPHICAL METHOD OF CALCULATING FAULT CURRENTS ON REA LINES

By

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U. S. Department of Agriculture

Rural Electrification Administration

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GRAPHICAL METHOD OF CALCULATING FAULT CURRENTS ON REA LINES

Introduction

The graphical method of calculating fault currents, described below, offers many advantages over other methods commonly used to make fault current calculations. Some of these advantages are as follows: (1) there is less chance for error; (2) considerable time and effort is saved in making the calculations; (3) a visual picture is obtained of the possible fault currents at any sectionalizing point or any intermediate point; (4) a compact permanent record is obtained; and (5) it provides an easy method of quickly calculating the fault currents for new taps or sections added to a system after the original study has been completed. The accuracy obtained by the graphical method is approximately equal to the accuracy obtained by exact mathematical calculation of fault currents, and it is considerably greater than the accuracy obtained by the use of any one of the special slide rules available for making fault current calculations.

Information Required

The following information is necessary before fault current calculations can be made by the graphical method:

1. Total resistance and total reactance, for both the maximum and minimum fault current conditions, on the lead side of the REA supply substation or at the metering point. It is necessary to know these resistance and reactance values for three phase, line-to-line, and line-to-ground faults and they must be referred to the line-to-ground voltage of the system.

2. Location of sectionalizing points on a key map of the system.

3. Phasing, mileages, and wire sizes between sectionalizing points and from the last sectionalizing points to the end of the most distant tap.

Description of Current Diagrams

The fault current calculations are made on current diagrams. Separate current diagrams are used for each fault current study, and these are made a part of the sectionalizing study file. Current diagrams are available for three phase, line-to-line, and line-to-ground faults on 7200 volt neutral grounded systems built to REA specifications. The 7200 volt current diagrams can be used for other system voltages, as explained on page two.

Referring to one of the attached current diagrams, you will notice that the background of the diagram is a rectangular coordinate system with resistance in ohms along the horizontal axis and reactance in ohms along the vertical axis. Superimposed upon the coordinate system, there is a series of

concentric quarter circles, each circle indicating a value of short circuit current. You will note that the current diagram is really the first quadrant of a current vector diagram with the line-to-ground voltage as the base voltage. Fault currents can be read on the circle at the intersection of the total resistance and the total reactance values of the circuit.

In the lower right-hand corner, there is a group of scales called "mileage scales," each scale representing a different copper equivalent conductor size. The length of line in miles is marked along each scale, starting from zero on the left end of the scale. The position of each mileage scale on the diagram and the calibration of each scale is governed by the per mile resistance and reactance values of lines built to REA specifications for each conductor size. The mileage scales are based on average values of resistance and reactance for the various types of conductor. The scale to which each mileage scale was drawn is the same as the scale of the rectangular coordinate system on the main part of the current diagram.

There are two current diagrams for line-to-ground faults, numbered 1 and 2, Current diagram No. 2 is a continuation of diagram No. 1 for use when it is found that the range of diagram No. 1 is not large enough to determine fault currents at all desired points on a system. There is only one current diagram each for three phase, and line-to-line faults, which will cover the range of three phase and line-to-line fault currents on REA systems.

Use of Data Sheet

Attached there is a copy of Form DS-89 which should be used for tabulating the data necessary to plot the fault current points on the diagram, and for tabulating the maximum and minimum fault currents. Each sectionalizing point on the system, and the most distant points beyond the last sectionalizing devices, should be designated on a key map by a letter or number. Then the data necessary to plot the points on the current diagram should be tabulated in the first five columns of the form. After the points have been plotted on the current diagram, the fault currents at 7200 volts phase to ground as read on the current diagram can be tabulated in the sixth and seventh columns. Columns eight and nine are to be used only when the system voltage is other than 7.2/12.5 KV. The columns on the right half of the form are the same as those on the left half of the form; in other words, the right half is a continuation of the left half.

Calculation of Fault Currents When System Voltage is Not 7.2/12.5 KV By Using Current Values Determined From 7200 Volt Current Diagrams

The current diagrams are all based on a line-to-ground voltage of 7200 volts; therefore, fault currents on 7.2/12.5 KV systems can be read directly from the current diagrams. For systems whose line-to-ground voltage is 6900 volts or any other voltage except 7200 volts, fault currents as read on the current diagrams must be corrected to the actual line-to-ground voltage.

The fault current at any location on a system is directly proportional to the line-to-ground voltage. Suppose a fault current study is being made on a system whose voltage is 6.9/11.9 KV. The fault currents as read on the

7200 volt three phase, line-to-line, and line-to-ground current diagrams must be multiplied by $\frac{6900}{7200}$ in order to obtain the actual fault current values.

The last two columns, columns eight and nine, on the data sheet are for use in tabulating the actual fault currents. If the line-to-ground voltage is not 7200 volts, multiply the fault current values read on the current diagrams, which have been tabulated in columns six and seven, by $\frac{\text{actual line-to-ground voltage}}{7200}$ and tabulate the actual fault currents in columns eight and nine.

Procedure For Calculating Short Circuit Currents on Current Diagrams

1. On the current diagram for the type of fault being calculated, locate the point for the total impedance of the source and REA substation by laying off the resistance along the horizontal scale and the reactance along the vertical scale. Locate the total impedance for both the maximum and minimum conditions. For the minimum condition on line-to-ground faults, be sure to add in the assumed value of fault resistance. Mark these two points $S_{max.}$ and $S_{min.}$

2. By manipulating two triangles or a ruler and a triangle, draw a line from $S_{max.}$ and from $S_{min.}$ to the right parallel to the mileage scale for the conductor size in the first section of line away from the substation. The easiest method of drawing this line is to lay the hypotenuse of a 30 - 60 degree triangle along the proper mileage scale. Then lay a ruler along the base of the triangle and slide the triangle up along the ruler until the hypotenuse of the triangle is on point $S_{max.}$ or $S_{min.}$ Draw the desired line along the hypotenuse of the triangle.

   Please note that an extended portion of each mileage scale has been placed in the right hand margin of the form, which will aid in lining up the triangle along the desired mileage scale.

3. Using a compass, or dividers, and the mileage scale for the proper conductor size, set the instrument to the number of miles from the substation to the first sectionalizing point. Lay this distance off from $S_{max.}$ and $S_{min.}$ along the line drawn in step two. Letter these points the same as the corresponding point on the sectionalizing map is designated.

4. Read the short circuit currents on the circles.

5. Repeat the above procedure for the next sectionalizing point farther out on the system, except that the mileage distance should be laid off from the last points plotted instead of from $S_{max.}$ and $S_{min.}$ If the next section is of a different conductor size, draw a new line on the diagram, parallel to the proper mileage scale. Repeat until all points on the system, at which short circuit current values are desired, have been plotted on the diagram.

6. For some systems, all line-to-ground fault current points can be plotted on current diagram No. 1. On other systems, the fault current points located a considerable distance from the substation will fall off of current diagram No. 1, in which case, current diagram No. 2 should be used. The last point that will fall on diagram No. 1 should be located on diagram No. 2 at the intersection of the resistance and reactance values for the point which can be read on the resistance and reactance scales of diagram No. 1. Then continue plotting points on diagram No. 2 as before. In the case of three phase and line-to-line faults, all fault current points can be plotted on one diagram.

Mileage Scales Not Given on Current Diagram

Mileage scales are given on the current diagram for the most commonly used conductor sizes. In cases where there is not a mileage scale for the conductor installed on the distribution line, a mileage scale can easily be drawn on the diagram. It is necessary to know the resistance and reactance of the line in ohms per mile for the type of conductor used and for the type of fault being calculated. Pick any convenient point several inches to the left of the mileage scales on the diagram. From this point, using the resistance scale on the diagram, lay off a distance to the right equal to the resistance of one mile of the line. From the point just located, lay off a distance vertically upward, equal to the reactance of one mile of the line. You will now have two legs of a right triangle, the hypotenuse of which is equal to the impedance of one mile of the line. Draw the hypotenuse and extend it upward to the right. The line drawn will be the mileage scale desired. Calibrate the scale in miles by marking off distances on the scale equal to the length of the hypotenuse of the small triangle. In order to obtain greater accuracy in plotting the mileage scale, it is suggested that ten times the per mile resistance and reactance values be used in laying off the triangle as explained above. Then subdivide the hypotenuse into ten parts.

Steel Conductors - The impedance of a line consisting of steel conductor varies considerably depending upon the amount of current flowing in the line, which makes it impossible to use one mileage scale for all values of fault current. The single phase impedance of a No. 4 or No. 6 Amersteel type 3S-130 conductor line carrying 100 amperes is approximately twice the impedance of the same line carrying a current of one ampere. However, for all values of current, the ratio of resistance to reactance for either a No. 4 or No. 6 steel conductor line is approximately the same as the ratio of resistance to reactance of No. 11 copper equivalent conductor. In other words, the slope of the mileage scales for these steel conductors would be the same as the slope of the No. 11 copper equivalent mileage scale on the current diagrams, which means the mileage scale No. 11 on the current diagram can be used for steel conductor lines provided that the calibration of the scale is corrected for steel conductor.

The procedure for plotting line-to-ground fault current points on the current diagram for steel conductor lines by correcting the mileage scale for No. 11 copper equivalent conductor is as follows:

1. From the current diagram determine the maximum (or minimum) fault current at the beginning of the section of steel conductor line in question.

Knowing the fault current at the beginning of the section, estimate the value of maximum (or minimum) fault current which will occur at the end of the section or at the fault point of the steel conductor section. In other words, estimate the fault current flowing in the steel conductor.

2. Select the proper "mileage correction factor" from the following table for the fault current at the end of the section as determined in step one. Interpolate if necessary.

MILEAGE CORRECTION FACTORS FOR AMERSTEEL STEEL TYPE 3S-130 CONDUCTORS (LINE-TO-GROUND FAULTS)

Line Fault Current In Amperes	Mileage Correction Factor For #4 B.W.G. Conductor Size	Mileage Correction Factor For #6 B.W.G. Conductor Size
10	1.23	1.58
20	1.39	1.67
30	1.62	1.95
40	1.85	2.45
50	2.06	2.96
60	2.25	3.06
70	2.25	3.00
80	2.20	2.94
90	2.16	2.85
100	2.12	2.74

For current values above 100 amperes use mileage correction factors for 100 amperes.

3. Multiply the "mileage correction factor" by the actual length of steel conductor line in the section. This gives a corrected mileage which can be plotted from the No. 11 copper equivalent scale.

4. Plot the fault current point on the current diagram for the end of the section of steel conductor by using the mileage scale for No. 11 copper equivalent conductor and the corrected length of the section as determined in step 3 above.

If you are unable to estimate the fault current at the end of the section, select a "mileage correction factor" for the first or second value of current listed in the table which is smaller than the fault current at the beginning of the section. Plot the fault current point for the end of the section, and from the current diagram read the value of fault current. Check to see if the proper "mileage correction factor" was used. If not, select a "mileage correction factor" for the new value of fault current at the end of the section and replot the point. Repeat until the assumed value and the actual fault current are approximately the same value.

A "mileage correction factor" is the ratio of the impedance of steel conductor for a given value of fault current to the impedance of No. 11 copper equivalent conductor. The correction factors given in the table are for line-to-ground faults on line consisting of Amersteel conductor. Some makes of steel conductor have slightly different electrical characteristics;

however, the correction factors given in the table can be used for all makes of steel conductors approved for use on REA systems. A fuse or breaker, which will operate satisfactorily on the bases of fault current calculations made as explained above, will be satisfactory on a line consisting of any one of the approved types of steel conductor.

Suggestion

A separate current diagram should be used for each substation on the system. In cases where one substation serves a large number of miles of line, and there are a large number of sectionalizing points, it is suggested that separate current diagrams be used for each one of the main feeders from the substation, in order to prevent confusion which may result from too many points on the same current diagram.

Attached there are copies of the data sheet, Form DS-89, and current diagrams for calculating three phase, line-to-line, and line-to-ground fault currents, Forms DS-90, DS-91, DS-92, and DS-93. Also attached there is a sample problem and the complete graphical solution for determining the line-to-ground short circuit currents at the various sectionalizing points.

Form DS-89

U. S. DEPARTMENT OF AGRICULTURE RURAL ELECTRIFICATION ADMINISTRATION	SECTIONALIZING STUDY Sheet .... of .... Sheets	Project Designation ....
Prepared by: .... Date	Checked by: .... Date	System Line-To-Gr. Voltage .... Volts

1 Point	2 Preceding Point On Line Toward Substation	3 Miles from Previous Point On Line Toward Substation	4 Copper Conductivity Size Section From Previous Point	5 Type of Fault Calculated	6 Maximum Fault Current Read on Current Diagram (7200 Volts Line-To-Ground)	7 Minimum Fault Current Read on Current Diagram (7200 Volts Line-To-Ground)	8 Actual Maximum Fault Current Col.No.5 x $\frac{\text{Line-To-Gr. Volts}}{7200}$	9 Actual Minimum Fault Current Col.No.7 x $\frac{\text{Line-To-Gr. Volts}}{7200}$

1 Point	2 Preceding Point On Line Toward Substation	3 Miles From Previous Point On Line Toward Substation/	4 Copper Conductivity Size Section From Previous Point	5 Type of Fault Calculated	6 Maximum Fault Current Read on Current Diagram (7200 Volts Line-To-Ground)	7 Minimum Fault Current Read on Current Diagram (7200 Volts Line-To-Ground)	8 Actual Maximum Fault Current Col.No.5 x $\frac{\text{Line-To-Gr. Volts}}{7200}$	9 Actual Minimum Fault Current Col.No.7 x $\frac{\text{Line-To-Gr. Volts}}{7200}$

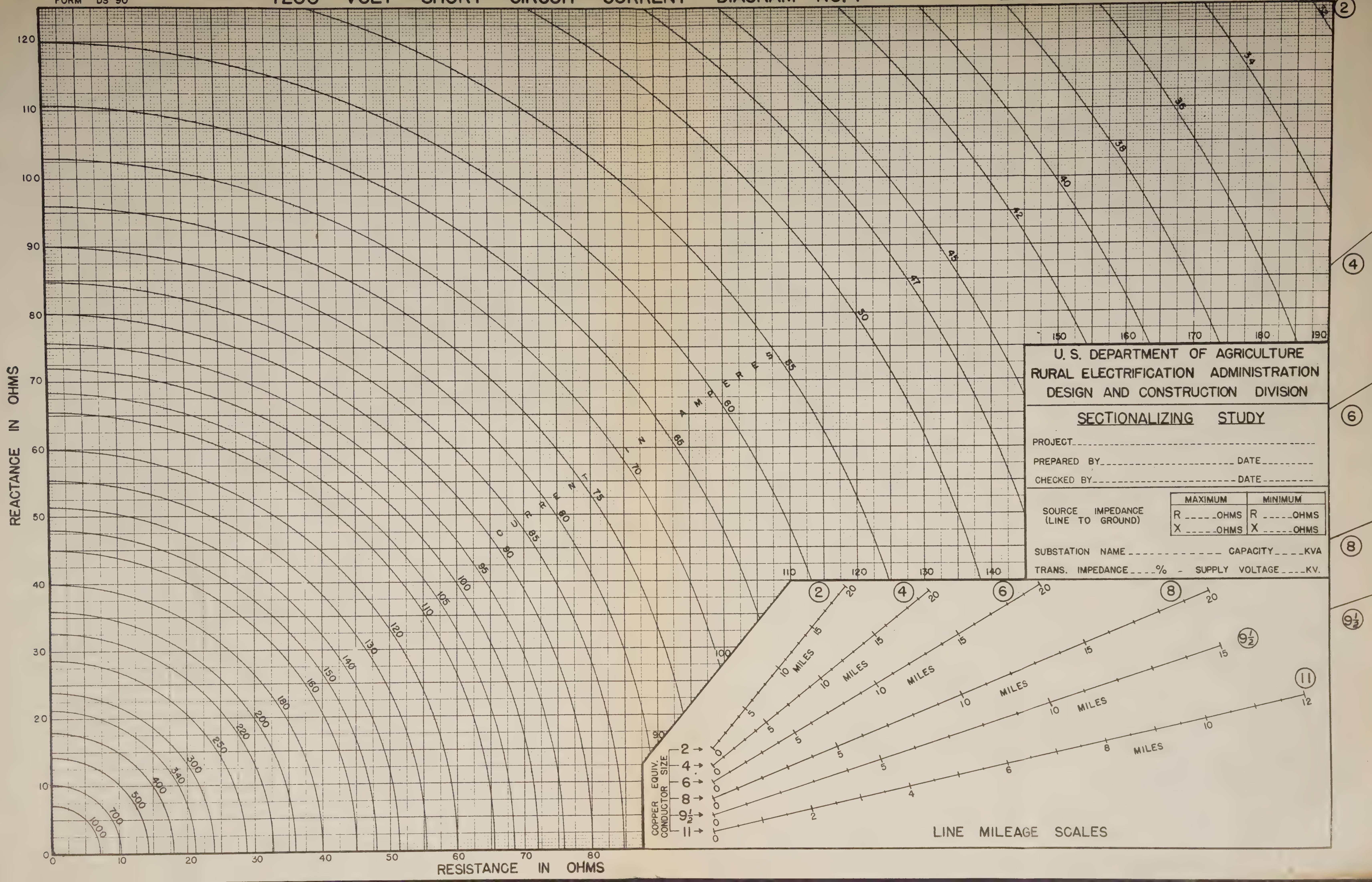
Note: Columns 8 and 9 are to be used only when system voltage is not 7.2/12.5 KV.

B-494

FORM DS-90

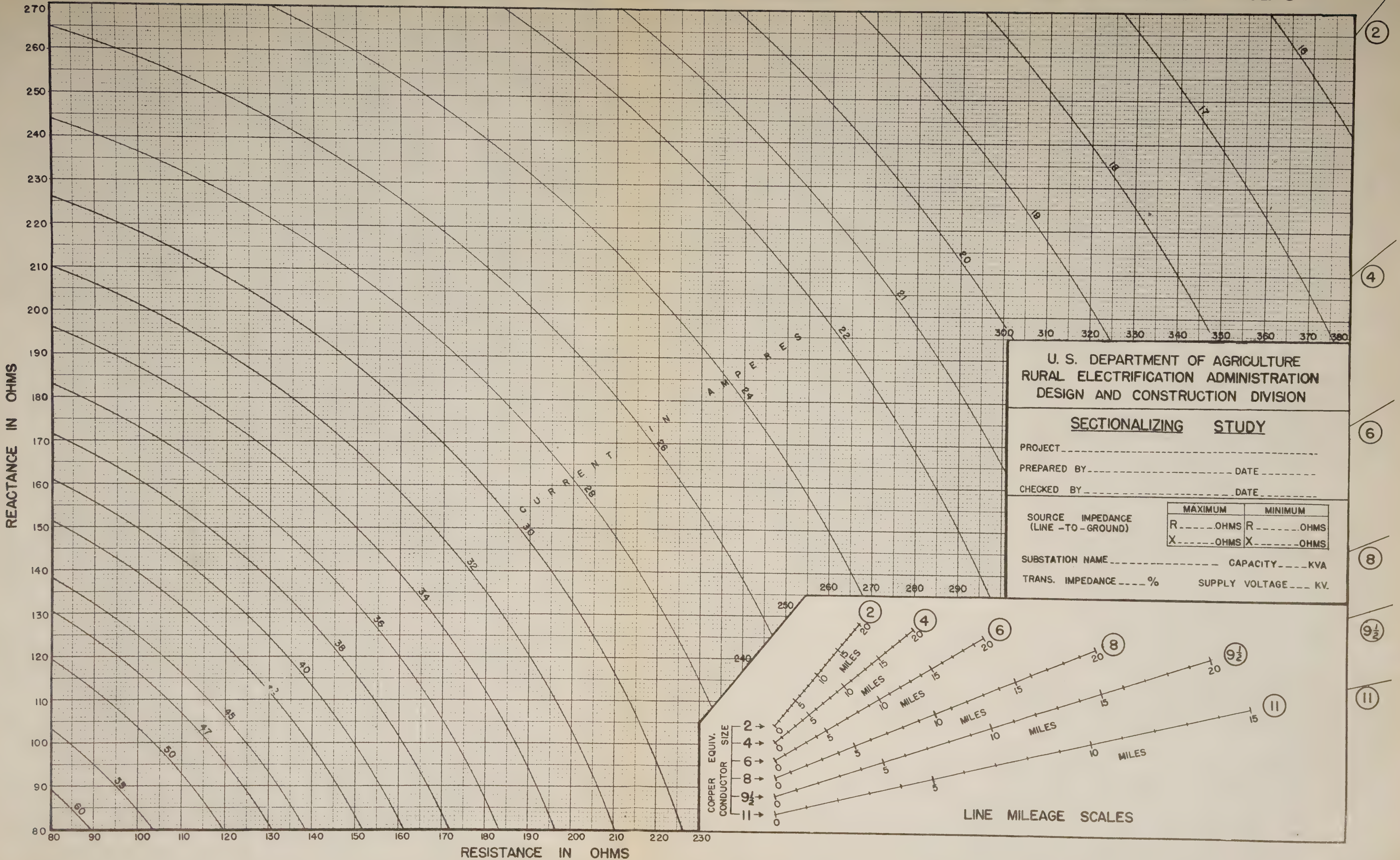
7200 VOLT SHORT CIRCUIT CURRENT DIAGRAM NO. 1

LINE-TO-GROUND FAULTS



FORM DS-92

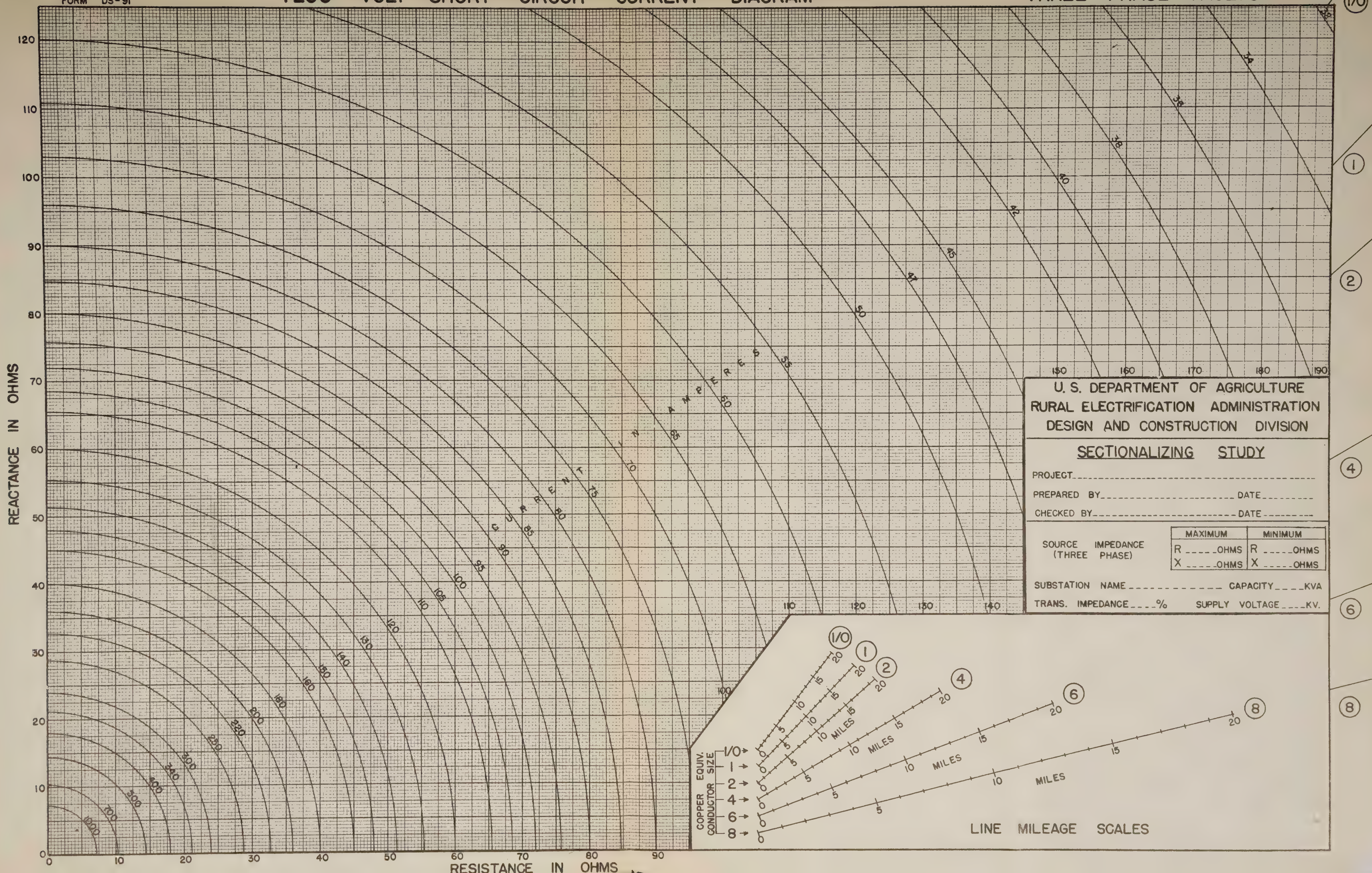
7200 VOLT SHORT CIRCUIT CURRENT DIAGRAM NO. 2 — LINE-TO-GROUND FAULTS



FORM DS-91

7200 VOLT SHORT CIRCUIT CURRENT DIAGRAM

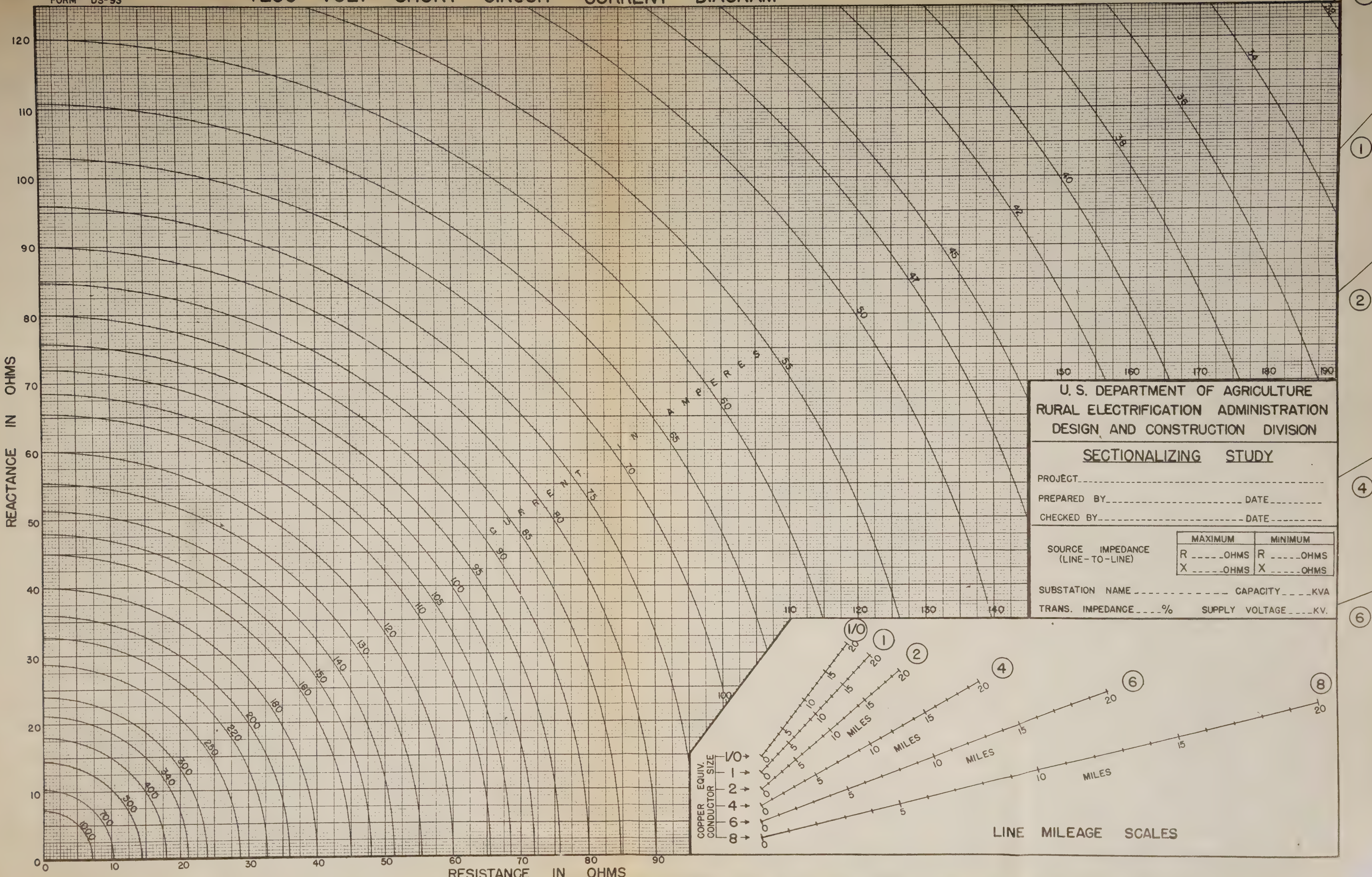
THREE PHASE FAULTS



FORM DS-93

7200 VOLT SHORT CIRCUIT CURRENT DIAGRAM

LINE-TO-LINE FAULTS



U. S. DEPARTMENT OF AGRICULTURE
RURAL ELECTRIFICATION ADMINISTRATION
DESIGN AND CONSTRUCTION DIVISION

SECTIONALIZING STUDY

PROJECT_______________________________________

PREPARED BY_________________________ DATE_________

CHECKED BY__________________________ DATE_________

SOURCE IMPEDANCE (LINE-TO-LINE)	MAXIMUM	MINIMUM
	R _____OHMS	R _____OHMS
	X _____OHMS	X _____OHMS

SUBSTATION NAME_____________ CAPACITY____KVA

TRANS. IMPEDANCE____% SUPPLY VOLTAGE____KV.

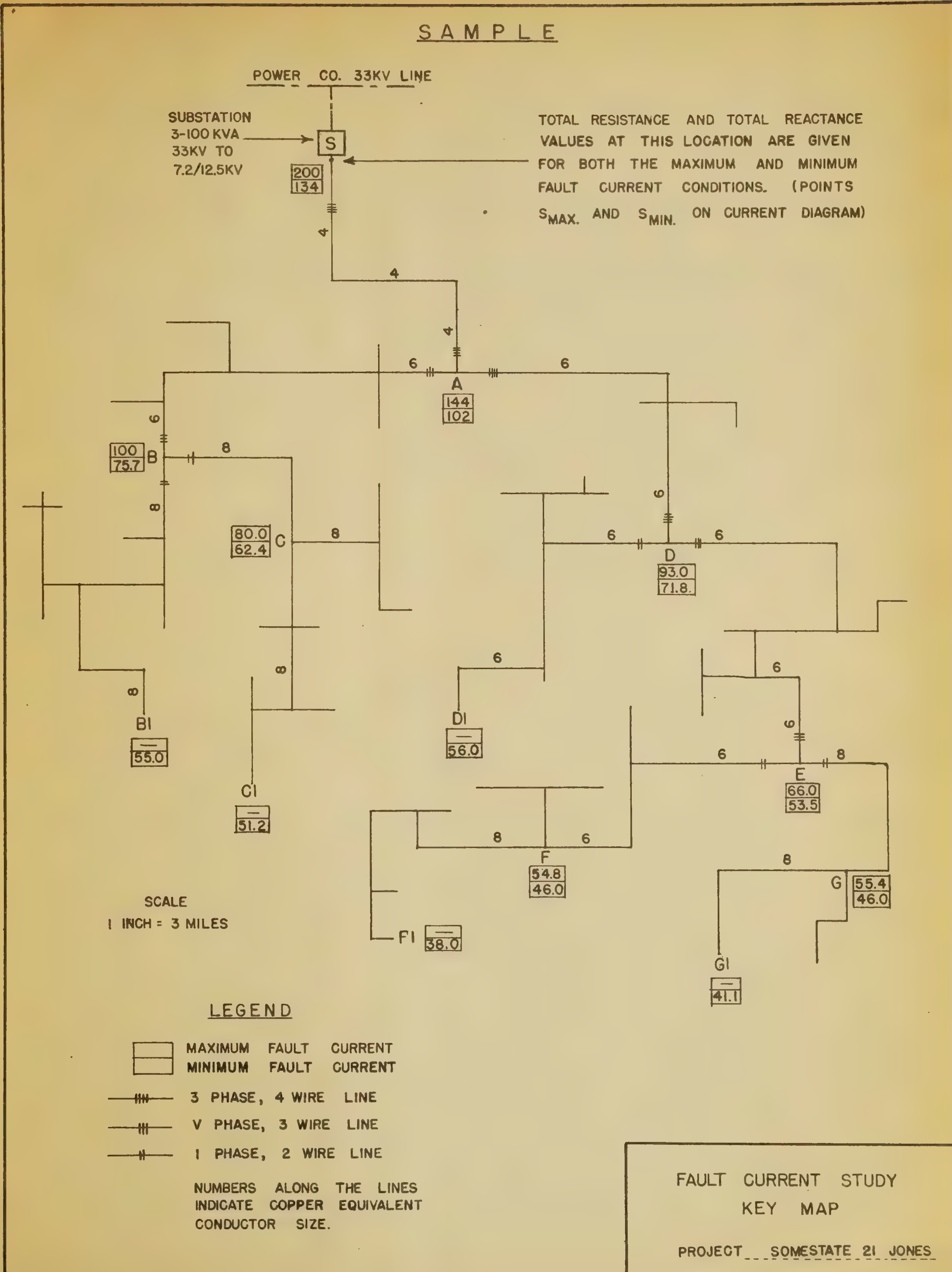
SAMPLE PROBLEM

This sample problem is given for the purpose of illustrating the procedure of calculating the line-to-ground fault currents by the graphical method. A hypothetical distribution system is shown on the attached simplified sectionalizing key map. A fault resistance of 30 ohms is assumed. The resistance and reactance values on load side of the substation for line-to-ground faults for both the maximum and minimum condition are as follows:

	Line-To-Ground Faults
Maximum Condition:	
Resistance..	5.5 ohms
Reactance...	35.6 ohms
Minimum Condition:	
Resistance (Includes 30 ohm fault resistance).....	35.5 ohms
Reactance...	40.5 ohms

A current diagram and data sheet for the sample problem, showing the complete solution for determining the line-to-ground fault currents, are attached. You will note that points were not plotted on the current diagram for the maximum fault current at the end of the most distant taps, since it is necessary to know only the minimum currents at those points.

Consideration is not given to three phase and line-to-line fault currents in the sample problem, in view of the fact that the procedure for calculating these currents is exactly the same as the procedure for determining line-to-ground fault currents. In making a sectionalizing study of an actual system which has three phase and V phase lines, three phase fault current calculations should be made for all points on the three phase lines using the three phase current diagram, and line-to-line fault current calculations should be made for all points on the three phase and V phase lines using the line-to-line current diagram. The starting points on the three phase diagram should be the total resistance and total reactance values for maximum and minimum conditions on the load side of the substation for three phase faults. The starting point on the line-to-line diagram should be the total resistance and total reactance values, for the maximum and minimum conditions, on the load side of the substation for line-to-line faults.


SAMPLE
POWER CO. 33KV LINE
SUBSTATION
3-100 KVA
33KV TO
7.2/12.5KV
S
200
134
TOTAL RESISTANCE AND TOTAL REACTANCE VALUES AT THIS LOCATION ARE GIVEN FOR BOTH THE MAXIMUM AND MINIMUM FAULT CURRENT CONDITIONS. (POINTS $S_{MAX.}$ AND $S_{MIN.}$ ON CURRENT DIAGRAM)
A
144
102
B
100
75.7
C
80.0
62.4
D
93.0
71.8.
E
66.0
53.5
F
54.8
46.0
G
55.4
46.0
B1
—
55.0
C1
—
51.2
D1
—
56.0
F1
—
38.0
G1
—
41.1
SCALE
1 INCH = 3 MILES
LEGEND
MAXIMUM FAULT CURRENT
MINIMUM FAULT CURRENT
3 PHASE, 4 WIRE LINE
V PHASE, 3 WIRE LINE
1 PHASE, 2 WIRE LINE
NUMBERS ALONG THE LINES INDICATE COPPER EQUIVALENT CONDUCTOR SIZE.
FAULT CURRENT STUDY
KEY MAP
PROJECT SOMESTATE 21 JONES

Form DS-89

(Sample Problem)

U.S. DEPARTMENT OF AGRICULTURE RURAL ELECTRIFICATION ADMINISTRATION	SECTIONALIZING STUDY Sheet 1 of 1 Sheets	Project Designation Somestate 21 Jones
Prepared by: Joe Blowe Date 11/8/43	Checked by: Date	System Line-To-Gr. Voltage 7200 Volts

1 Point	2 Preceding Point On Line Toward Substation	3 Miles from Previous Point On Line Toward Substation	4 Copper Conductivity Size Section From Previous Point	5 Type of Fault Calculated	6 Maximum Fault Current Read on Current Diagram (7200 Volts Line-To-Ground)	7 Minimum Fault Current Read on Current Diagram (7200 Volts Line-To-Ground)	8 Actual Maximum Fault Current Col. No. 6 X $\frac{\text{Line-To-Gr. Volts}}{7200}$	9 Actual Minimum Fault Current Col. No. 7 X $\frac{\text{Line-To-Gr. Volts}}{7200}$
Sub				Line-To-Ground	200	134		
A	Sub.	8.2	#4		144	102		
B	A	9.0	#6		100.0	75.7		
B1	B	9.3	#8		-	55.0		
C	B	5.2	#8		80.0	62.4		
C1	C	6.7	#8		-	51.2		
D	A	11.0	#6		93.0	71.8		
D1	D	9.8	#6		-	56.0		
E	D	12.0	#6		65.0	53.5		
F	E	7.9	#6		54.8	46.0		
F1	F	8.3	#8		-	38.0		

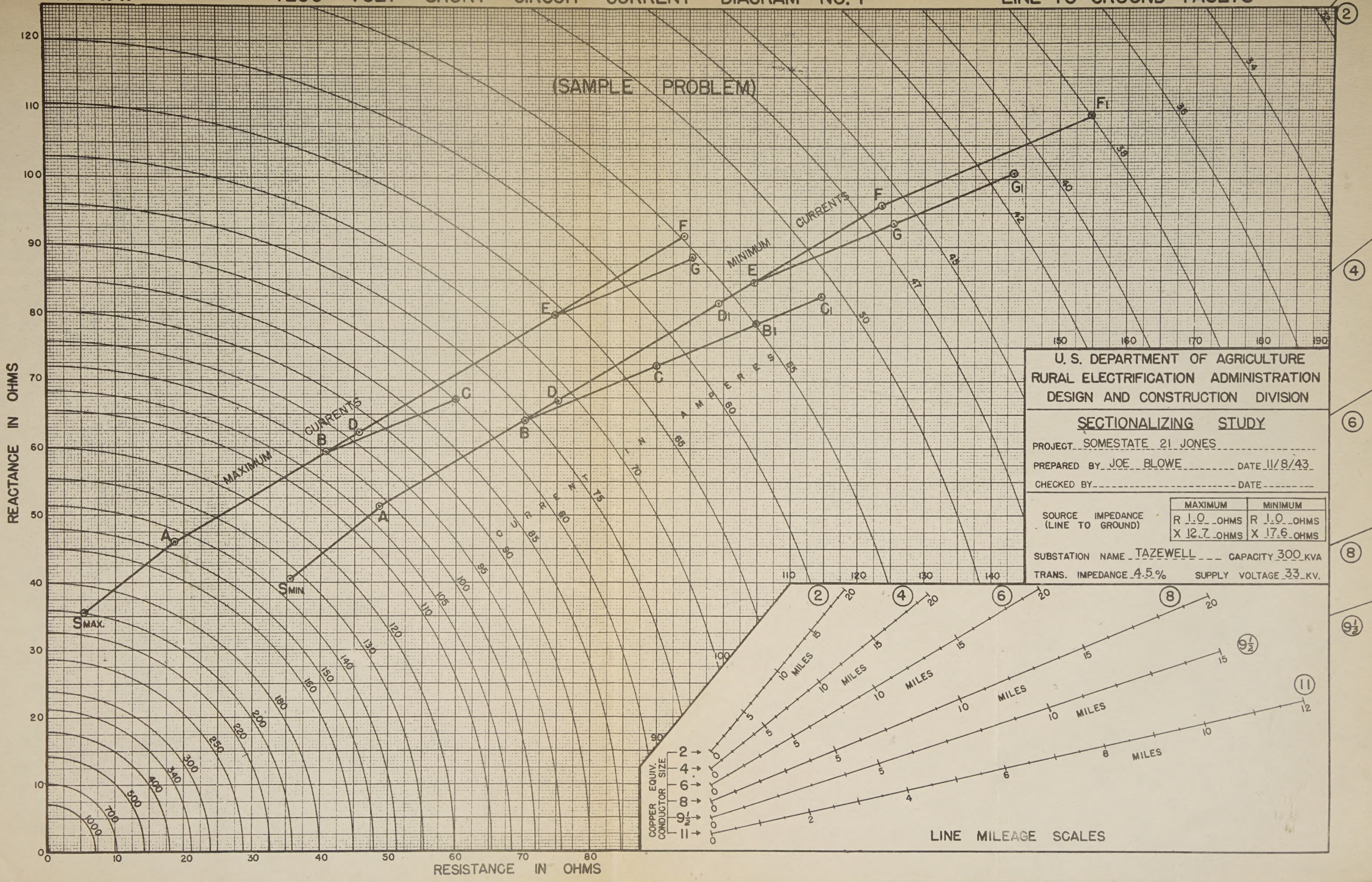
1 Point	2 Preceding Point On Line Toward Substation	3 Miles from Previous Point On Line Toward Substation	4 Copper Conductivity Size Section From Previous Point	5 Type of Fault Calculated	6 Maximum Fault Current Read on Current Diagram (7200 Volts Line-To-Ground)	7 Minimum Fault Current Read on Current Diagram (7200 Volts Line-To-Ground)	8 Actual Maximum Fault Current Col. No. 6 X $\frac{\text{Line-To-Gr. Volts}}{7200}$	9 Actual Minimum Fault Current Col. No. 7 X $\frac{\text{Line-To-Gr. Volts}}{7200}$
G	E	5.5	#8	L. to Gr.	55.4	46.0		
G	G	4.8	#8		-	41.1		

Note: Columns 8 and 9 are to be used only when system voltage is not 7.2/12.5 KV.

C-219

FORM DS-90

7200 VOLT SHORT CIRCUIT CURRENT DIAGRAM NO. 1 — LINE-TO-GROUND FAULTS



U. S. DEPARTMENT OF AGRICULTURE
RURAL ELECTRIFICATION ADMINISTRATION
DESIGN AND CONSTRUCTION DIVISION

SECTIONALIZING STUDY

PROJECT SOMESTATE 21 JONES

PREPARED BY JOE BLOWE DATE 11/8/43

CHECKED BY ____ DATE ____

SOURCE IMPEDANCE (LINE TO GROUND)	MAXIMUM	MINIMUM
	R 1.0 OHMS	R 1.0 OHMS
	X 12.7 OHMS	X 17.6 OHMS

SUBSTATION NAME TAZEWELL CAPACITY 300 KVA

TRANS. IMPEDANCE 4.5% SUPPLY VOLTAGE 33 KV.